# Geochemical Characteristics of Volcanism on the Azores

Senior Thesis

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By


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## Abstract

Ocean islands are ideal research areas for petrologists because of their volcanic origins and the geochemical information they reveal of the mantle underneath. The Azores archipelago is no exception, lying within a unique geological setting which contains a mantle plume as well as tectonic plate boundary movement. Supported by these facts, the islands are an interesting and valuable place to study igneous petrology. By using major oxide data from the separate Azores, variation diagrams can be produced to display trends between different chemical ratios. Differences or similarities seen can be attributed to magma mixing, the complex plumbing system of the mantle plume, and the geographic placement of the islands near major tectonic features.

## Acknowledgments

I would like to thank Dr. Barton for his guidance throughout this senior thesis. His supervision and patience were a much needed resource, and for that I am immensely grateful. I would also like to show gratitude towards Mitch Modlich for his help with the CoHort Software, which was immeasurable. Lastly, I'd like to express appreciation towards the Max Planck Institute for Chemistry in Mainz, who maintain the internet database GEOROC, a fantastic resource which I couldn't have done this project without.

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# Introduction

For being a small set of islands located in the middle of the Atlantic Ocean, the Azores archipelago is one of the most geologically active places on Earth (Figure 1). Along with being near three major tectonic plate boundaries, petrologists are able to study the volcanism present on all nine islands. The Azores are also considered to have a hotspot origin, despite their proximity to seafloor subduction (White et al., 1979). Unlike Hawaii though, which is also of hotspot origin, they do not have clear chronological order with respect to their geography. Comprising the Western Group is Flores at 2.16 million years old (Myr) and Corvo at 0.7 Myr. Faial is 0.7 Myr, Pico is 0.27 Myr, Sao Jorge is 0.55 Myr, Graciosa is 2.5 Myr, and Terceira is 3.52 Myr, making up the Central Group. Forming the Eastern Group is Sao Miguel with 4.1 Myr, and Santa Maria with 8.12 Myr (Carine et al., 2010).

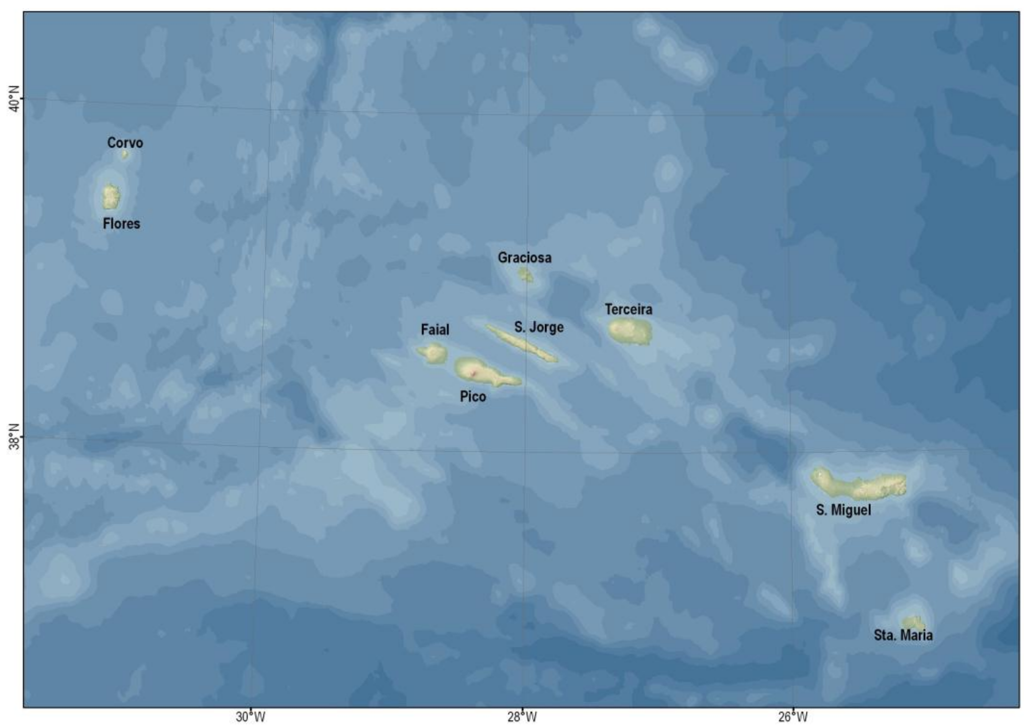



**Figure 1: The Azores divided into the Western, Central, and Eastern Groups (Earthzine)**

This unique circumstance can help geologists understand several situations at once without having to leave the area. Geochemistry is one of the best and most important subjects to study here, since it can help determine where and how this archipelago formed. My Senior Thesis hypothesizes that by researching the chemistry of volcanic rocks on each of the islands, we will be able to establish a history of how the Azores formed and where they continue to evolve. Major oxides will be the focus of my thesis, but other areas should be considered in later studies, such as trace elements and radiogenic isotopes.

## Objectives

The overall objective of this research project is to better understand the geological relationship between the separate Azores islands based on the chemistry of their volcanic rocks. This can be achieved by graphically showing their major oxide compositions and comparing them afterwards. The computer program CoHort is a good program to help with this task because it visualizes the data effectively and is able to put multiple data sets on graph arrays for easy analyzing. CoHort Software can also give each island its own symbol and color, helping to catch incongruities between the two that are contrasted while finding patterns within the archipelago.

## Geologic Setting

The Azores started to form nearly 8 million years ago during the Miocene, and are located in the North Atlantic Ocean near the triple junction of the North American, Eurasian, and African lithospheric plates (França et al., 2006). One of the main tectonic features is the Mid-Atlantic Ridge (MAR), which runs between the islands of Flores and Faial. Along with the MAR, the Terceira Rift (TR) trends along Graciosa, Terceira, and Sao Miguel, while the Gloria Fault (GF) extends eastwardly from Santa Maria (Machado et al., 2008). The East Azores Fracture Zone (EAFZ) constitutes the western portion of the GF and is due south of the archipelago (Figure 2). Lying on a plateau, the islands are formed from volcanic activity due to a mantle plume underneath the oceanic crust. Seismic activity continues to be prevalent in the area, mainly from the MAR and the TR (Beier et al., 2006).

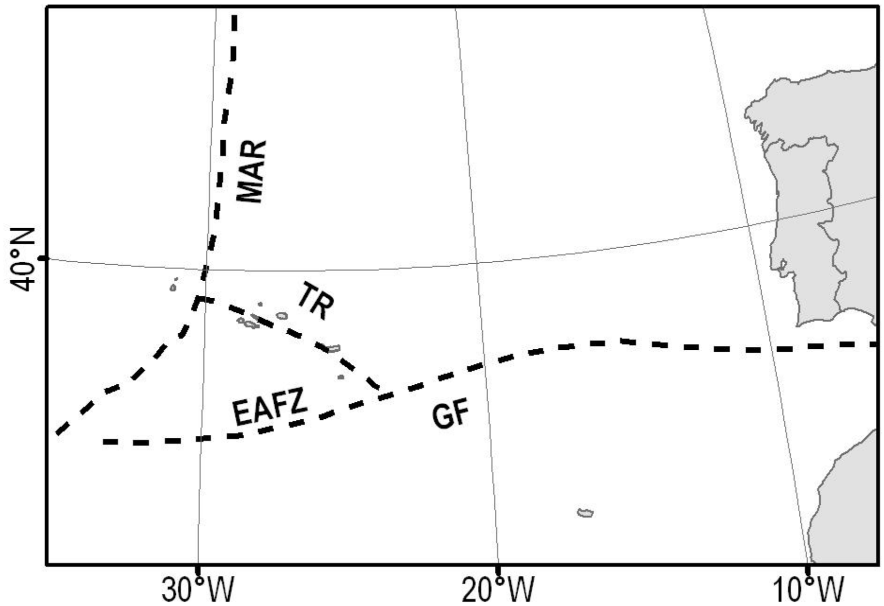



**Figure 2: Tectonic setting of the Azores (Earthzine)**

## Methods

Major oxide percentages were found using sample analyses from the database GEOROC (Geochemistry of Rocks of the Oceans and Continents). By refining the search down to only the specific islands, separate excel sheets could be attained and given their own data files. Volcanic rocks were only studied during this experiment.

CoHort Software was utilized to plot the data graphically. The major oxides were each given a scatter plot with magnesium oxide (MgO) on the x-axis, because of its constant removal from basalts during their evolution. Each island was then shown against Sao Miguel, the largest island and the one with the most data. This was done so the trend would be easily discernable.

## Results and Discussion

The graphs showed a good amount of variation between the islands as compared to Sao Miguel (Black Triangles), and gave good insight to their differences and similarities. Terceira is the next largest island by land area and had the most data available besides Sao Miguel. The ferrous oxide (FeOT) graph appeared to have an upward shift from the normal trend, while the potassium oxide ($K_2O$) trend shifted downward (Figure 3). All other oxides for Terceira showed a similar orientation with Sao Miguel with little to no change. Sao Jorge had an analogous effect, with FeOT and $K_2O$ having the same dissimilarities as Terceira (Figure 4).

Pico Island was different though, with sodium oxide ($Na_2O$) deviating higher and phosphorus pentoxide ($P_2O_5$) moving lower (Figure 5). $K_2O$ was again shifted down, while FeOT stayed with normal trend.  A corresponding outcome was seen with Faial, this time including aluminum oxide ($Al_2O_3$) in a definite higher position (Figure 6). The island Graciosa had the least amount of data in the Central Group and consequently didn’t reveal any points that lied outside the range of Sao Miguel (Figure 7).

Santa Maria, the closest island to Sao Miguel geographically, was uniform in each graph with the exception of calcium oxide (CaO) which had a few lower points lying beneath the general trend (Figure 8). The Western Group, consisting of Flores and Corvo Island, was combined due to their lack of data (Figure 9). No differences could be seen throughout their graphs.

The Central Group of islands had the largest variances when contrasted with Sao Miguel, meaning that lavas may be produced by a chemically independent source (White et al., 1979). Tectonically they are further away from the GF than the Eastern Group, and could have different rates at which the volcanic rocks are formed. This could also explain the difference between Santa Maria and Sao Miguel. The meeting point of the GF, TR, and EAFZ is closest to Santa Maria, and would affect the basalts around the island.

This does not explain though the high similarity between the oxide data of the Western Group to Sao Miguel. Geographically they are the furthest apart, as well as the MAR tectonically separating them. The scarcity of plotted points could be a reason for their comparability. Another could be mixing within the mantle, although this would mean greater differences between the three. Further research should be done to see how, through isotope and elemental analyses, the island groups are linked chemically and how tectonics and magma mixing play a role in their evolution (França et al., 2006, Beier et al., 2006).

**Figure 3: Terceira (Grey Circles)**

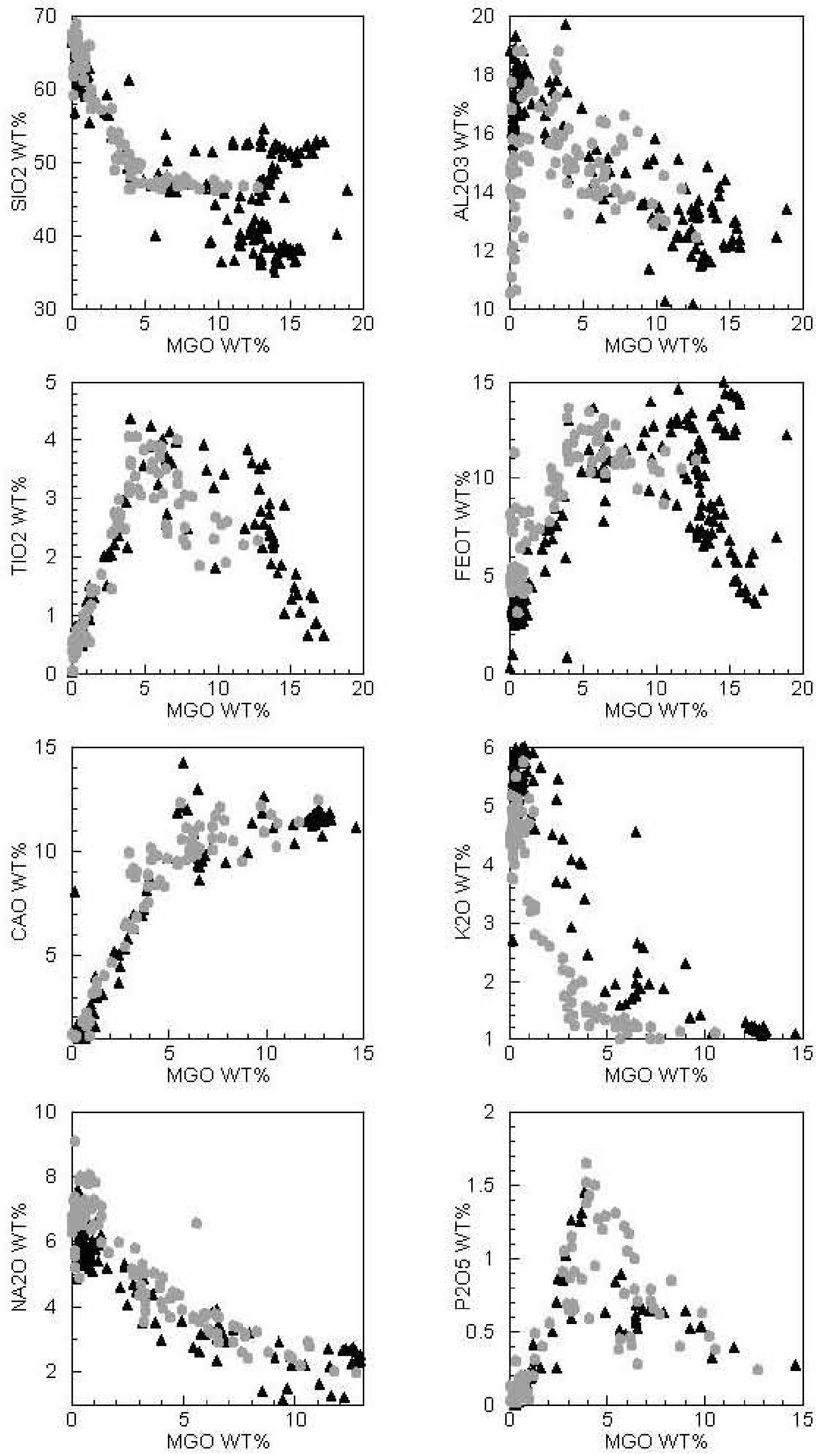


**Figure 4: Sao Jorge (Grey Squares)**

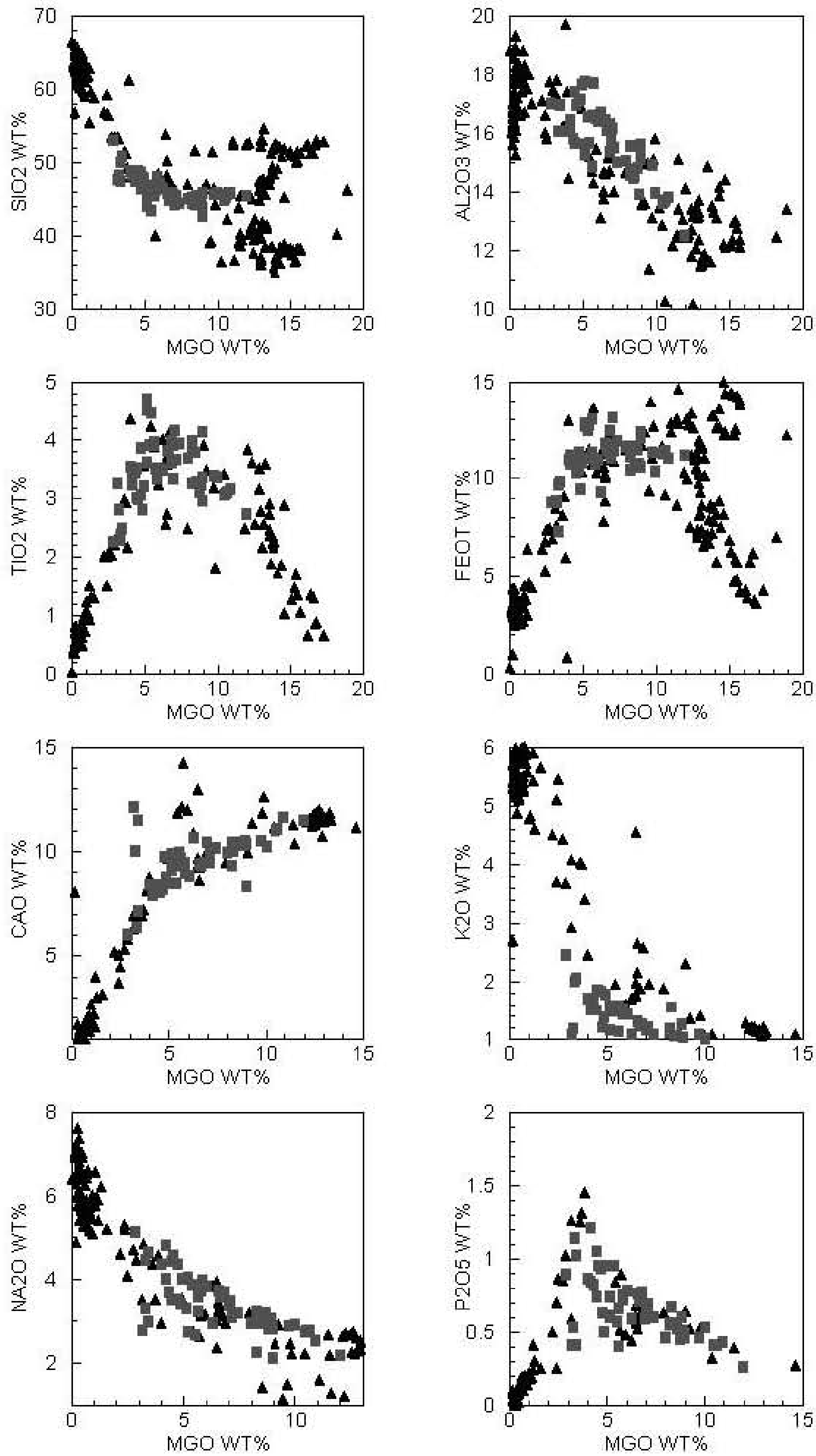


**Figure 5: Pico (Grey Upside-Down Triangles)**

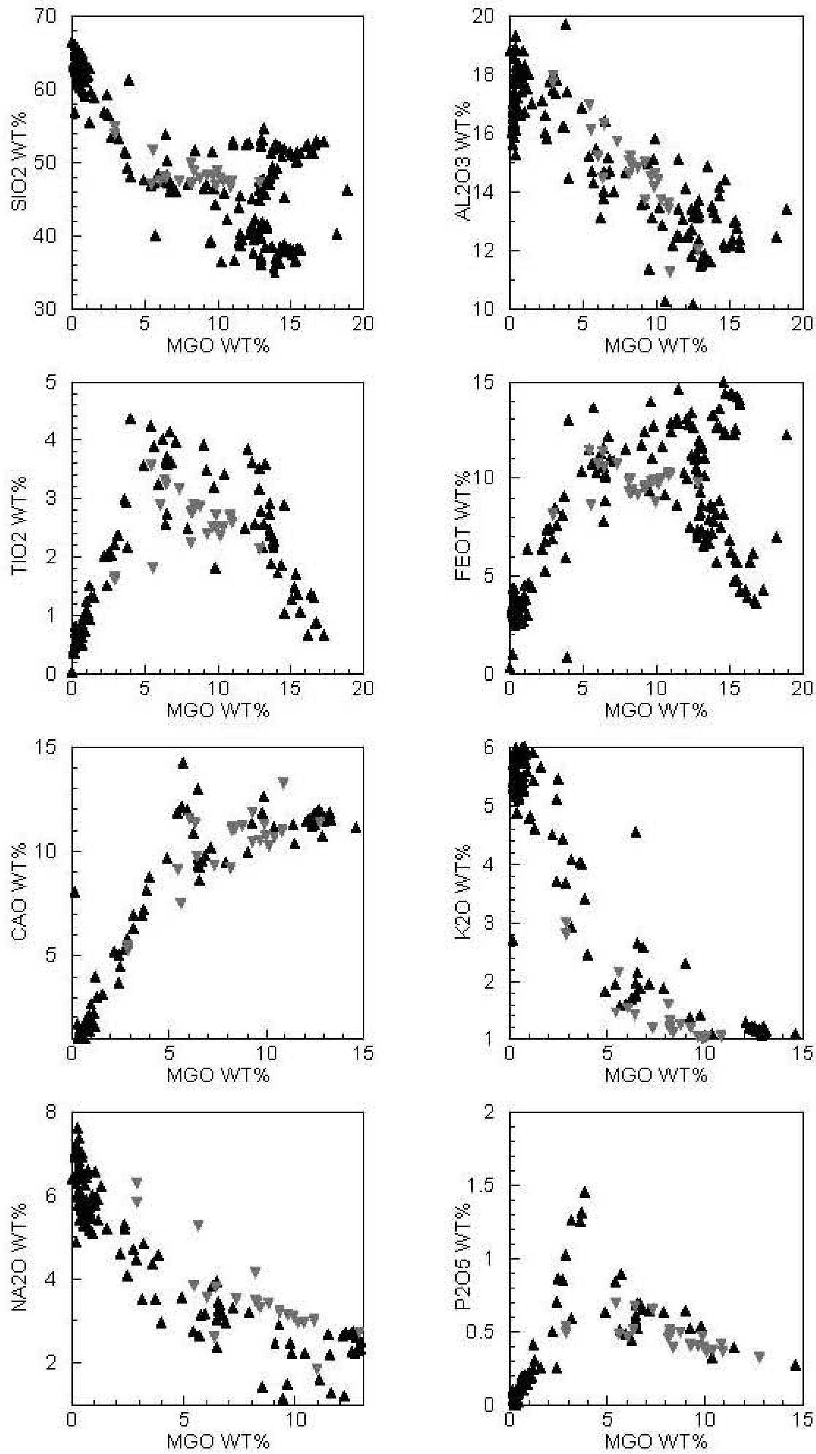


**Figure 6: Faial (Grey Parallelograms)**

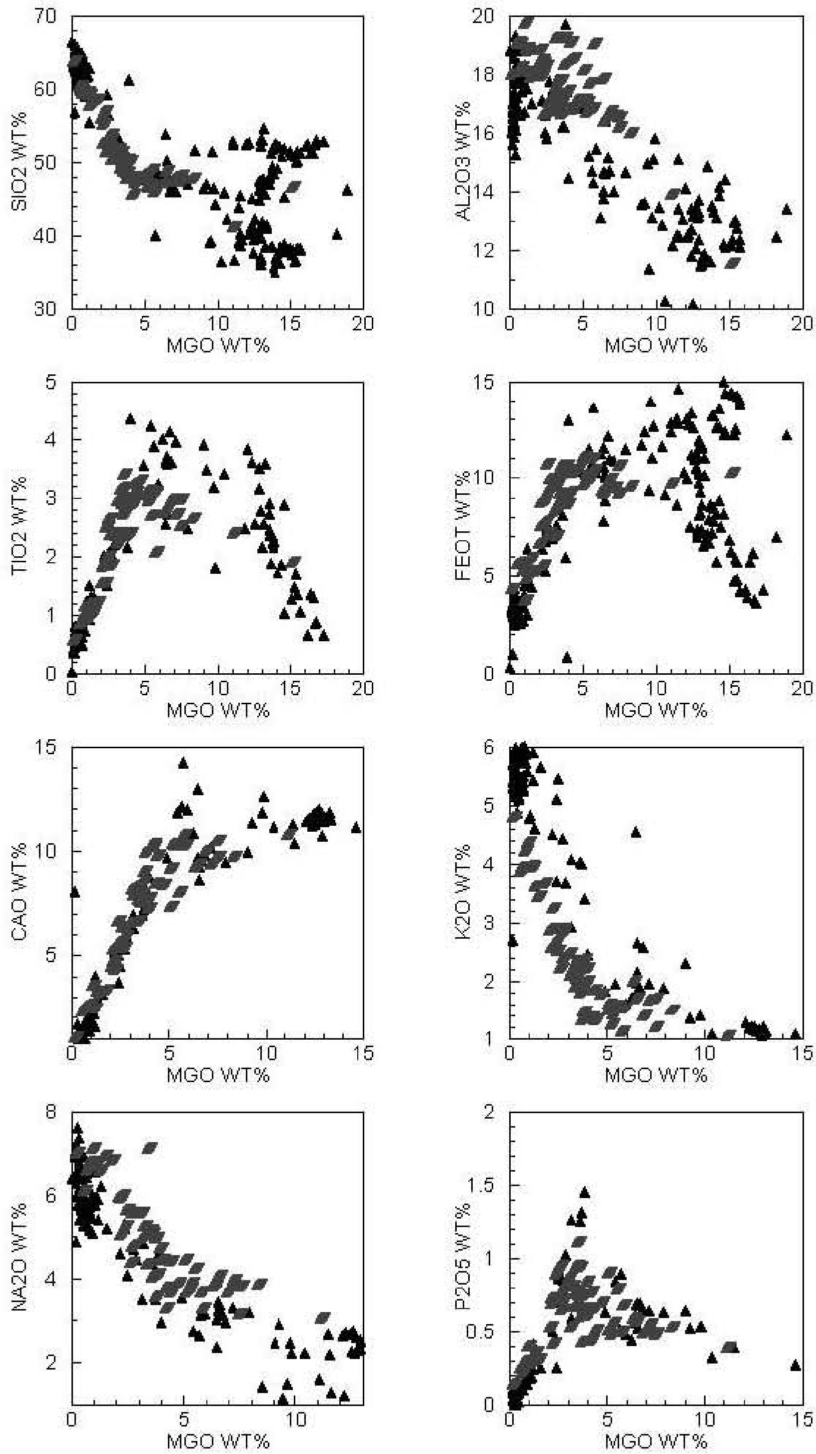


**Figure 7: Graciosa (Grey Diamonds)**

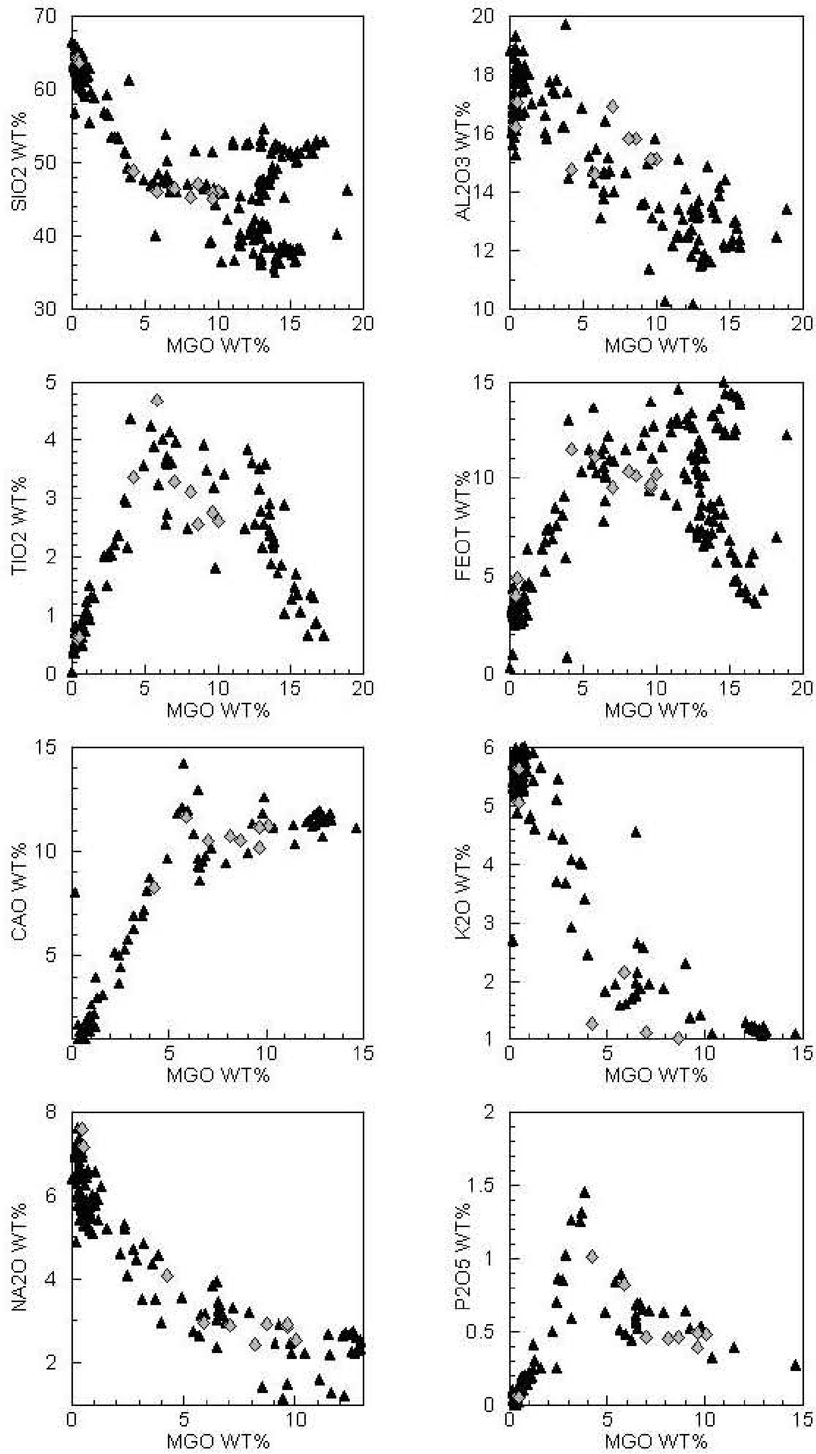


**Figure 8: Santa Maria (Grey Dots)**

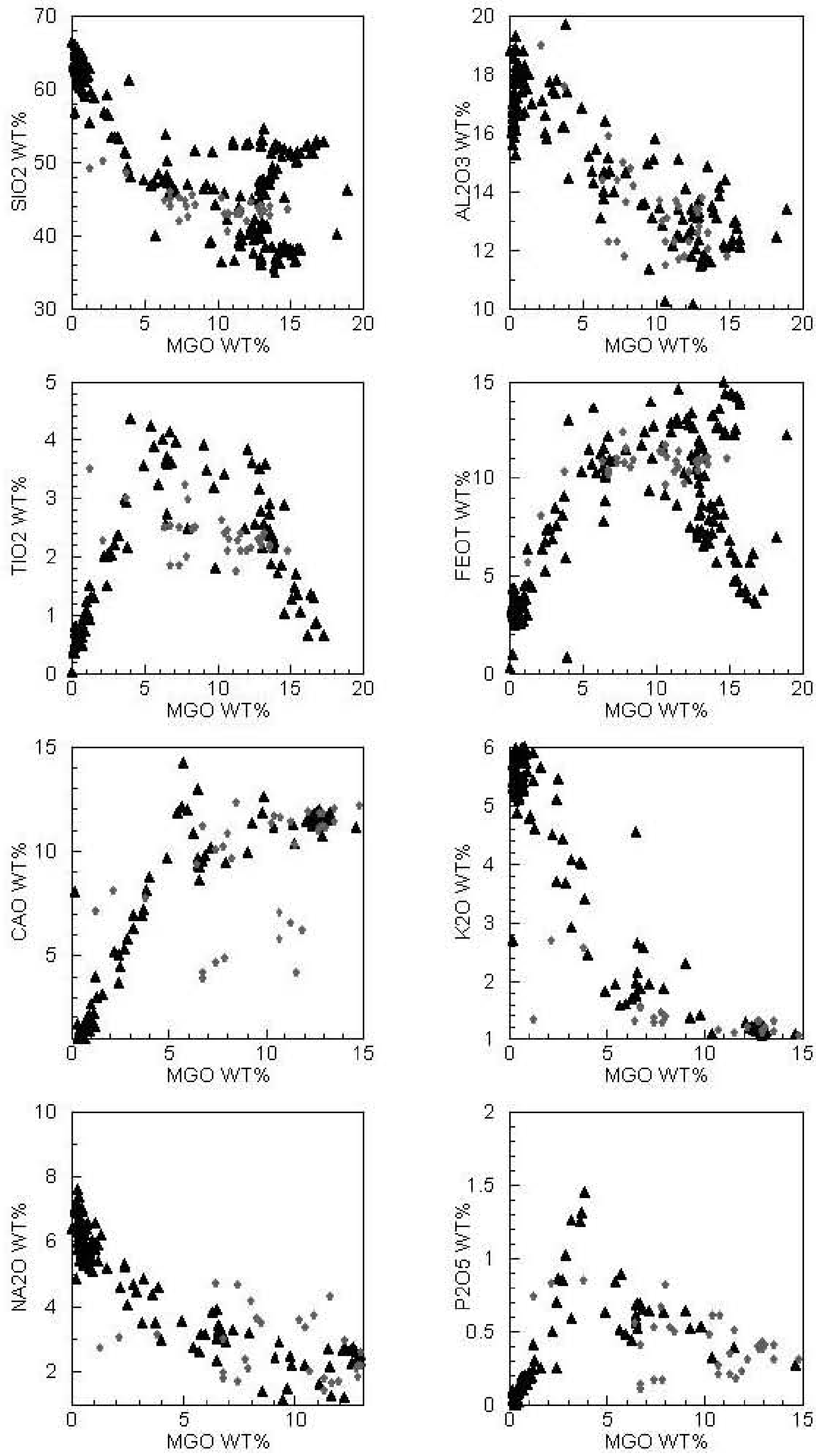
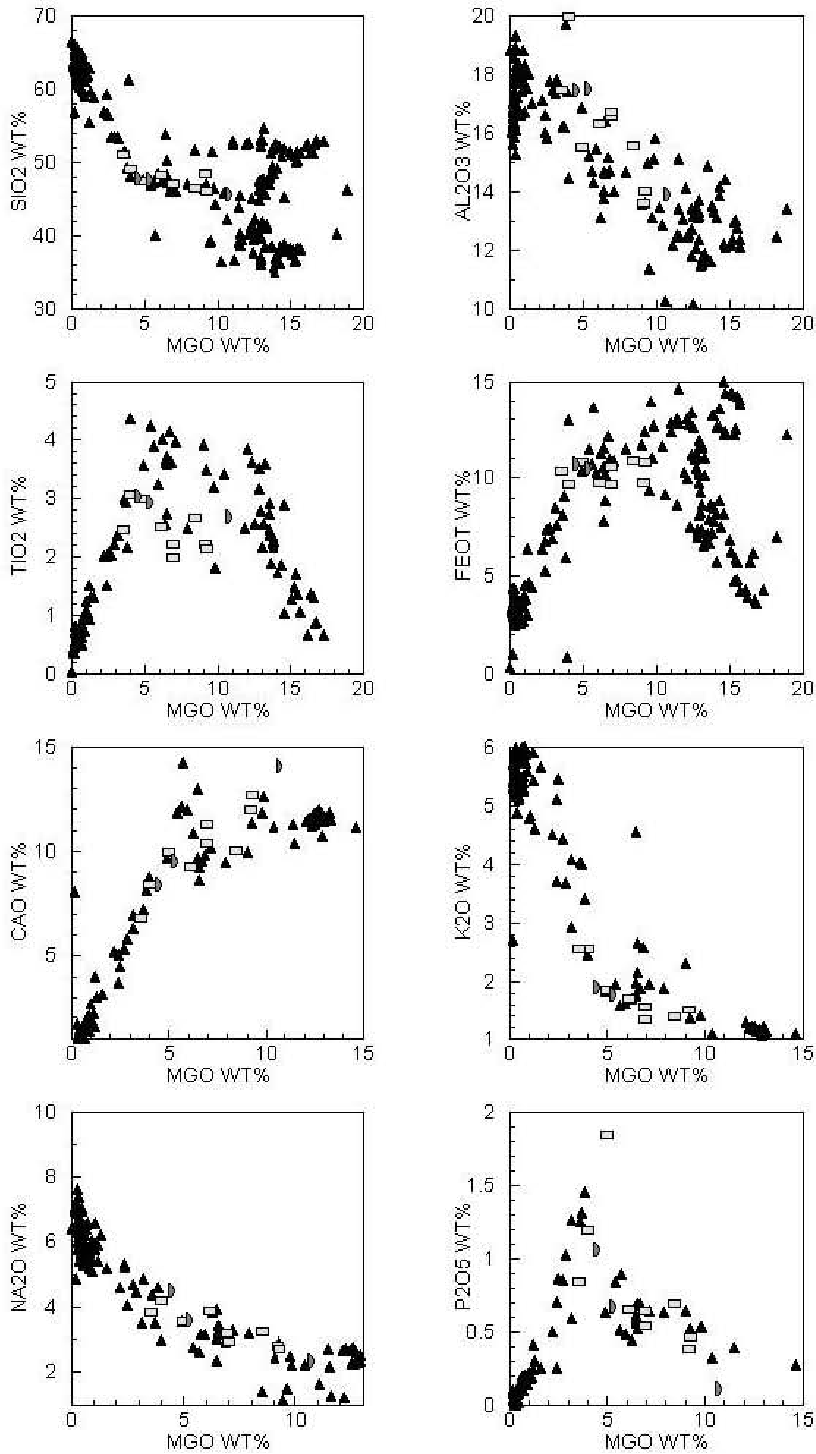


**Figure 9: Flores (Grey Rectangles) and Corvo (Grey Half Circles)**



## Conclusions

Eight major oxides were studied for all nine islands of the Azores archipelago, with an emphasis on the contrast between the chemical compositions of Sao Miguel and the others. Differences were observed on nearly all the islands, exceptions being made for Graciosa, Flores, and Corvo because of their absence of possible data. The Central Group of Terceira, Sao Jorge, Pico, and Faial saw considerable deviations from trends set by Sao Miguel. Santa Maria saw little change aside from the CaO data. Judging from their oxide characteristics alone, an explanation for these relationships could be related to their geologic position with tectonic plates, volcanic activity, and mixing within the mantle plume beneath the Azores (França et al., 2006, Beier et al., 2006).

## Further Research

Concerning the Azores, much study is still needed in deciphering the different chemical compositions for each separate island. I didn’t have enough time to study the major and trace elements found on each island, which would’ve helped to identify the larger differences amidst the archipelago. The next step would be to look at isotope ratios, and to look beyond only volcanic rocks. A more in depth approach to the tectonic setting would prove beneficial during the next phase of research, especially when assessing the issue of mantle mixing and recycling and how it relates to the islands chemical content. In a broader sense, researching the complex undersea tectonic setting surrounding the Azores could help other parts of science, such as seismology, mineral physics, and oceanography.

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